THE EFFECT OF BUILDING FORM ON COOLING LOAD IN HOT AND HUMID CLIMATE

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To the Most Gracious and Merciful,
and to my beloved mother and father

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ABSTRACT

High energy consumption correspondingly starts from an inefficient use of energy. The communities are increasingly concerned towards a better usage of energy for more comfortable life in future. Since past decades the standard of living has improved, people tend to expect a better comfort level which they consider the usage of air conditioning system is a must. The design of a building is required to provide comfort and efficient energy usage. The research objectives are to study the concept and influence of building form and geometry, investigate the cooling load in building space and to explore building form strategies in decreasing the cooling load. The research investigates the development and relationship of basic geometrical building form in lowering cooling load of a medium five-storey building. The manifestation of different thermal behaviour of each basic form was based on different volume, height and surface. The study manipulates the variables in three steps. The first step is the exploration and understanding of basic forms having the same height level, volume and different surface. The second step is investigating further on basic form by having different height levels but same overall volume. The final step explores the same volume, height level and surface area of the geometric forms. The study was conducted using computer simulation analysis program Autodesk Ecotect 2011. The outcome of the research reveals that compact shape and lower ratios of surface to volume result in lower cooling loads. The building with a different floor height but same overall volume shows the effect of lowering the cooling load. The increase number of floor zones will give lower cooling load. Experimentation of the basic forms reveals that an exposed surface area plays a huge role in lowering cooling load. Compact arrangement of spaces in a building also gives impact towards cooling load. The result of simulation model analysis shows the orientation aspect is less significant with 0.5 to 0.6 % difference towards lowering the cooling load compared to the exposed surface area of the form that shows 5 up to 19 % difference of cooling load from each geometry form. This research is significant in helping to accumulate the information regarding building form behaviour. Based on the result, the manipulation of exposed surface of the basic building form will reduce the cooling load.

ABSTRAK

Ketidakcekapan penggunaan tenaga dalam bangunan telah menyebabkan peningkatan kos penggunaan tenaga yang tinggi. Masyarakat semakin prihatin dalam membantu ke arah kecekapan penggunaan tenaga dan kehidupan yang lebih selesa di masa hadapan. Selaras dengan peningkatan taraf hidup, masyarakat semakin cenderung untuk menikmati tahap keselesaan yang lebih baik. Maka, penggunaan sistem penyaman udara dalam bangunan adalah satu kemestian dalam menikmati keselesaan. Objektif kajian adalah memahami konsep dan pengaruh bentuk geometri dalam reka bentuk bangunan, menyiasat beban penyejukan dalam sesebuah ruang dan meneroka strategi bentuk bangunan dalam mengurangkan beban penyejukan. Penyelidikan ini mengkaji pembangunan dan hubungan bentuk bangunan asas dalam mengurangkan beban penyejukan bangunan sederhana tinggi lima tingkat. Manifestasi sifat haba yang berbeza bagi setiap bentuk adalah berdasarkan perbezaan isi padu ruang, ketinggian aras dan permukaan bentuk. Kajian ini memanipulasi pemboleh ubah dalam tiga langkah. Langkah pertama ialah penerokaan dan pemahaman bentuk asas yang mempunyai ketinggian aras dan isi padu yang sama, tetapi jumlah permukaan yang berbeza. Langkah kedua menyiasat reka bentuk asas mempunyai ketinggian aras yang berbeza tetapi jumlah isi padu ruang yang sama. Langkah terakhir meneroka reka bentuk asas yang mempunyai isi padu ruang, ketinggian aras dan luas permukaan yang sama. Kajian dijalankan dengan menggunakan program Autodesk Ecotect 2011. Hasil kajian mendapati bahawa reka bentuk bangunan yang padat dan nisbah antara luas permukaan dan isipadu yang rendah menurunkan beban penyejukan. Bangunan yang mempunyai perbezaan bilangan tingkat tetapi isi padu yang sama menunjukkan beban penyejukan yang lebih rendah. Penambahan zon penyejukan pada satu aras juga menunjukkan penurunan beban penyejukan. Dapatan dari eksperimen reka bentuk bangunan asas menunjukkan luas permukaan terdedah memainkan peranan yang besar dalam menurunkan beban penyejukan. Susun atur ruang yang padat di dalam bangunan juga memberi kesan terhadap beban penyejukan. Hasil analisis model simulasi menunjukkan orientasi adalah kurang penting dengan perbezaan 0.5 hingga 0.6 % ke arah pengurangan beban penyejukan berbanding luas permukaan terdedah yang menunjukkan 5 hingga 19 % perbezaan nilai beban penyejukan. Kajian ini penting dalam membantu pengumpulan maklumat mengenai reka bentuk bangunan asas. Berdasarkan keputusan kajian, diandaikan bahawa manipulasi ruang permukaan terdedah suatu reka bentuk bangunan asas akan membantu dalam mengurangkan beban penyejukan.

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LIST OF ABBREVIATIONS

ANSI	-	American National Standards Institute
ASHRAE	-	American Society of Heating, Refrigerating and Air Conditioning Engineers
BTU	-	British Thermal Unit
CIBSE	-	Chartered Institution of Building Services Engineers
DOE	-	Department of Energy (United States)
GFA	-	Gross Floor Area
gbXML	-	Green Building Extensible Markup Language.
HVAC	-	Heating, Ventilation & Air-Conditioning
hp	-	Horsepower : unit measurement of power
IESV	-	International Energy Standards Value
IESNA	-	Illuminating Engineering Society of North America
IES	-	Integrated Environmental Solutions
OTTV	-	Overall Thermal Transfer Value
RTTV	-	Roof Thermal Transfer Value
SHGF	-	Solar Heat Gain Factor
S/V	-	Surface to volume ratio
UTM	-	Universiti Teknologi Malaysia
W/L	-	Width to length ratio
WWR	-	Window to wall ratio
WYEC	-	Weather Year for Energy Calculations

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CHAPTER 1

INTRODUCTION

1.1 Background of the study

Building cost is rising each year in the preliminary design, construction, maintenance, and life-cycle cost. There have been many studies on how to lower down the cost of material selection, the method of construction, and others. Building life cycle cost includes water, electricity, maintenance bills, and others. Electricity is one of the major causes that hikes up the building life cycle cost. Based on Economic Transformation Program Handbook 2010, government buildings and houses in Malaysia used air conditioning the most with 44% of contribution to the hikes of electric bill compared to other electrical appliances. Similar to a study in 2006 of 15 Month Awareness, Action and Result Monitoring Project for Secondary Schools in 2009 by CETDEM – Center for Environment, Technology & Development, Malaysia under Secondary School Energy Efficiency Action Project stated that air conditioning has taken up nearly 45% of electricity consumption and the largest electricity consumption in household. Meanwhile an audit by GreenTech Malaysia on the energy consumption in Malaysian building office reveals that 64% of energy is consumed by air conditioning, 12% by lighting, and 24% by general equipment (Aun, 2009; Chong et al., 2015) . This shows that building industry consumes a lot of energy. According to Malaysia Institute of Architect (PAM) and Malaysia Energy Commission, office or commercial buildings use nearly 64% of total energy only for air conditioning and essentially 70% of overall energy used can be saved by implementing energy efficient building design. In most institutional and office building, having air conditioning is a necessity especially in sustaining and enhancing the thermal comfort of space or building (Kwong et al., 2014). Previous study showed that air-conditioning and artificial lighting represent 50-60% and 20-30% of consumption, respectively; and there are the two main contributors of total electricity used in air-conditioned buildings (Li et al., 2002 ; Nikpour et al., 2011). In Malaysia, the commercial offices engaged with air conditioning systems take up an average of 70% of the total energy consumption yearly (Suziyana et al., 2013). Most surveys and studies have revealed air conditioning as the major reason for high energy consumption in a building.

Having the sun all year means building surfaces are constantly exposed to solar heat which is the major source of heat generation. Most tropical climate countries like Malaysia, Thailand, Singapore, and Indonesia have direct exposure to solar gain throughout the year. The need for comfort in this location means either installing air conditioning system or ensures better design of a building. If a building is designed in such a way that it enhances energy efficiency and comfort, the building can cool itself. There is no need to install large and expensive air conditioners. Smaller and fewer air conditioners mean significant less energy consumption and more savings on electricity bills. People always imagine energy efficiency in terms of its appliances and components such as electrical and lighting appliances, a sensor system, and controlled ventilation. However, these devices can be installed and planned even after the building is constructed and completed. The focus is not just on the installation of the equipment but on how to save the energy during the design process instead. The strategy in the design process that leads the architects to design a building within the shape and form that contributes to a better design with less energy consumption.

In designing the appropriate air conditioning system, the engineer will calculate the building cooling load. The cooling load is the quantity of heat energy that needs to be eliminated from space in order to preserve the temperature by cooling mechanisms or air conditioning systems. The cooling load calculation will directly influence the building cost along with the operating indoor air quality, occupant comfort, energy efficiency, and building durability. Based on Energy Efficiency and Renewable Energy US Department, the mechanical engineer should consider the critical inputs when proposing the air conditioning system. By considering these critical inputs, they can gather the information for cooling load calculation. The critical inputs are the design condition, orientation, internal condition, and internal load. The focus of this research would be initiating passive design strategies such as designing the building to ensure less heat gain, proposing the better placement of envelope, facade, shape or form of the building, and selecting the best material with good insulation quality. Most of these elements can be controlled by the architect's decision.

A lot of design strategies have been attempted to encourage energy efficiency and reduce energy consumption. By starting to design using the optimum form, it is one of the strategies to encourage the best design practice in relation to energy efficiency. This research explores optimize building form and its component, that illustrates less heat gain and low cooling load. With the increasing pollution and decrease of energy sources, identifying building performance is necessary, how and what kind of building form can perform efficiently and economically. The Malaysian government has introduce Green Building Index (GBI) to ensure a building meet the minimum requirement of energy efficient, not only focusing on the aesthetic and profit based. Designing with energy performance in mind will alter how the building will be operated, designed, and functioned; and this would be a demanding task.

1.2 Problem Statements

Architects would normally design a building based on the client's request, authority requirements, and aesthetically pleasing to the human perception. The anticipated energy performance and the initial cost of the design would not be an issue in the early design stage, as this matter is usually considered and rethink later when the design is already formed. Critical decisions that affect the energy performance and comfort level are frequently organised during the conceptual phase. Within the time constraint, the team needs to make a choice from various design options. This makes the evaluation process of building performance quite challenging and difficult (Tzempelikos et al., 2007). Architects usually have problems in determining the best option of building form and its components when they start initialize their early ideas. Their design is usually based on their experience and fundamental knowledge (Bleil de Souza, 2012). Most of the architect's rational design decisions are based on their previous experience in practice or education and knowledge from manuals and reference books which suggest some qualitative approach towards building design problems (Radford & Gero, 1980). There are extensive technical research results that are possible to be interpreted and made access to the architects for the application in the design process (Dean Hawkes, 1996).

The process in designing is constructivist, in which the design is solely based on experience. It may lack precise methods and structure integration. Furthermore, there are other problems such as satisfying the client's need. Most building designs are proposed based on the client's need without concerning the local climate or preserving energy, thus makes the building more dependent on artificial and consumes more energy (N. Al-Tamimi & Fadzil, 2012). However, if the client insists on energy efficient building, the building design would surely apply energy efficiency that adapt to its surroundings and turn out to be a green building. Nevertheless, it is still the architect's responsibility to educate their clients about energy efficiency building.

Experimentation in the design process would allow the architect to update their knowledge, create a few solutions for a problem, then manipulate and test different ways of applying their knowledge in solving design problems. In addition, experimentation on existing building is another way to identify energy and thermal performance of a building. In most cases, the focuses in the early design stage would be on the types of building, the building orientation and the layout on site, the user, the activities, and the number of users for each space. It is quite difficult to confirm whether these ideas would correspond to a design that is constructible, energy efficiency or cost-effective; or having actual proposed materials as this maybe cannot be done in the early design stage (Zarzycki, 2011). Hence, most building today are experiencing low efficiency which leads to excessive energy consumption, higher life-cycle cost, thermal comfort problems, and insufficient daylighting or too much glare. The insufficiency is often the consequences of the incapability of architects to deliberate various design options in an organised way (Sweeney, 2008). Obviously, this cannot be performed in the early stage because energy performance analysis usually comes with the results in graphs and tables showing the temperatures and load associated with the surface and volumes. Definitely, for an architect these data are meaningless. An architect usually wants to know the results of the associated load and temperature to the building elements in a way they can manipulate it graphically (Bleil de Souza, 2012; Olgyay, 1973).

An architect does not need to know the graph and tables showing the analysis but use the guidelines and strategies instead to get an optimized form from the research. Such strategies and elements that could improve by optimizing building form such as width and length geometrical manipulation, orientation, shading devices, window to wall ratio, width to length ratio, surface to volume ratio, and insulation material. These ideas can be easily applied in the early design process to achieve better building performance. Actually, a building life cycle cost and electricity bills can be cut down to a few percent as certain building forms or shapes contribute in reducing cooling load. Building forms, spatial layouts, and arrangement configurations that are planned towards energy efficiency and based on climatic data are considered as passive response. Improvisation of energy used is not only on building orientation but influenced by the form of the building and the ratio of volume to surface (Yeang, 2006). Basically, the size and orientation of exterior envelope are exposed directly to outdoor environment. These elements are determined specifically by the building form which in turn affects the thermal performance of a building. The building form also influences the cost and aesthetics. Undeniably, the selection of optimum form, orientation, and envelope configuration can reduced energy consumption by 40% (Mohammed Hussein Abed, 2012; Wang et al., 2006).

In common design process, an architect will start to draw and design from scratch. Using the information of the site weaknesses, strength, and orientation, the architect starts designing the building form that he/she perceives as good, optimum, and aesthetically pleasing to the eye and the mind. This research addresses the need for optimized design form and its components as a guide for an architect to start designing their initial ideas by implementing the optimum building form that enhances energy efficient potential and resolves the issues related to energy performance in the early design process. The responsiveness of energy consumption and environmental issues in a building can be translated using architectural science studies which are later developed into design tools that can assist the architect in designing responsively (Marsh & Arts, 1995). The research provides alternative and contribution to the body of knowledge related to building form, shape, and geometry. Therefore, through the variations of building form, the research would provide wider selections and opportunities of efficient and sustainable design for architects.

1.3 Research Questions

The specific research questions are:

1. What are the effective building form and its components that can influence towards lowering the cooling load in hot humid climate?
2. How does a building form can reduce the cooling load and improve the building energy efficiency in hot humid climate?

1.4 Research Aims

The aim of the research is to investigate the building form and its geometrical influence in reducing solar radiation absorption which leads to the decrease of cooling load using energy analysis. When designing, an architect can develop and manipulate the design based on the building form that can reduce the cooling load of the building.

To achieve this aim, the following objectives are formulated:

1. To understand the concept and influence of building form and geometry in building design towards achieving energy efficiency;
2. To investigate the cooling load in building space for basic geometrical building form; and

3. To explore building form strategies in improving energy efficiency in decreasing the cooling load.

1.5 Scope and Limitation of the Research

The scope of this research is to identify the building form from the chosen basic form in relation to cooling load. There are two main variables, the form and the building parameters analysed based on dependent variable cooling load. Then, the limitation of this research will be discussed.

1.5.1 Form

Appearance of a building is identified by its form, shape or geometry. Shapes and forms are considered as a manipulation of geometry that is commonly found in architecture and industry. Architectural form exist in the existence of building mass and space volume. Configuration of shapes in a volume is identified as building mass (Baker, 1996). Basically, shape is flat and considered as an outline of an object in 2 dimensional while form refer to a three dimensional object that has length, width and depth. Box is considered as the basic and simplest form of construction which can be manipulated and generated in other types of forms such as L, H, U, and T-shape (Pascal et al., 2006). The basic forms proposed in this research as shown in Figure 1.1 are based on Le Corbusier works, a basic principle of form space and order, and a basic typical commercial building form (Baker, 1996; Ching, 2007).

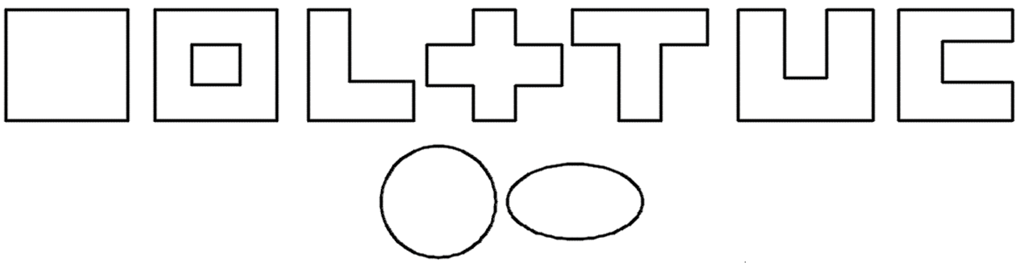

Figure 1.1 : The basic forms proposed in a plan view

The basic forms analysed are based on the rules and fundamental knowledge in architecture. These basic shapes are the forms that will be used and analysed in simulating various building forms. Form has width, length and depth, by having depth means form has surface and volume, surface will be one of the element that influence heat gain of a building form. Surface changes will affect the cooling load of a building form. The simulation will analyse the dissimilarities or changes of cooling load in the preliminary stage of building form design process.

1.5.2 Influence of Form towards Cooling Load

This study investigates the manipulation of basic shape and form on a medium five-storeys building of an institutional building in hot and humid climate and its impact towards the cooling load. Medium rise building is between 4 to 10 storeys. Five-storeys building data will be significant enough for the research scope. High rise building will give other different result and added more time to be analyse. The significant observation is how the cooling load differs as the building variables are changed and controlled. Form and shapes should conform to their own climate and surroundings, as building form and construction are the great influence in identifying the heating and cooling load requirement of a building (DeKay & Brown, 2001; Olgyay, 1973). It is important to gather the right data and information pertaining the optimum form that corresponds to energy performance specifically the cooling load and the computational analysis should conform to the local climate. The study focuses on five-story height buildings in Malaysia which fully use air-conditioning system, under the influence of hot and humid climate. The shape of the building to be analysed as a basic form is based on the result from literature study. In order to accomplish the objectives, this study analyses specific alternative forms and design ideas within the parameter of Autodesk Revit and Ecotect Analysis. It assumes that various building forms will give different cooling load calculation based on the building surrounding and the local climate.

1.5.3 Calculation of Cooling Load

Cooling load is the quantity of heat energy that needs to be removed from a space in order to preserve the temperature by a cooling mechanisms. The collection of heat gains that need to be eliminated is shown in Figure 1.2. Once all data collected, the formula will calculated how much of cooling load needed to preserve the temperature needed in a space. In this research, internal heat gain such as equipment, lightings, and people is being controlled in the simulations. While the external heat gain data which is extracted data from the Malaysia weather data is being calculated in finding the cooling load of each basic manipulated forms. External heat gain involve major heat gains from roof, wall and its opening. The basic building forms in this research will make the roof design constant and exclude the heat gain from the window. This is to ensure the result of the cooling load is specifically related to the manipulated basic building form by excluding data from other variables.

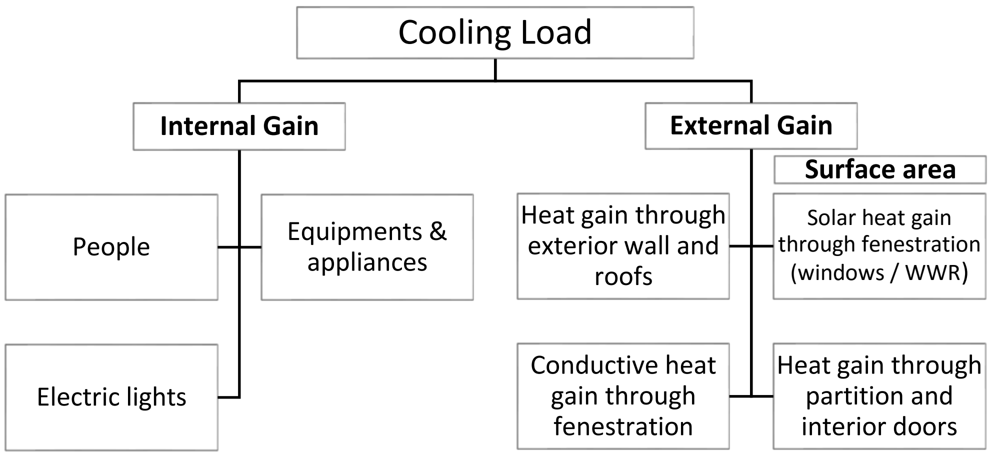

Figure 1.2 : Cooling load internal and external heat gains

The cooling load will be calculated using energy analysis software. The energy analysis software that calculates the cooling load will be carried out using Autodesk Ecotect 2011 but to ensure its validity as stated by Olgyay (1973), the building forms and shapes should follow the adverse impact of its thermal environment, so different shapes and forms are the results from its corresponding surrounding. The form is created by Revit and analysed by Ecotect; and the analysis is based on local weather data. The form typology and its components correspond to its local climate and site context. From there, the result of cooling load data can be compared and analysed.

There are various ways in calculating cooling load; however, the cooling load in Ecotect software is calculated using the CIBSE Admittance Method. CIBSE Admittance Method is used due to its fast and dynamic calculation, which will be a benefit for energy modelling in the early design process. The basic procedure for calculating the cooling load involves the engineer knowledge in building characteristic such as building material and components, building's location, its orientation and adjacent building, weather data, indoor conditions, schedule of lightings, equipment, and occupants, the framework is highlighted in Figure 1.3 shows the building characteristic and its variables involved in the research. Once all the data are gathered, the specific time and month are chosen to calculate the cooling load based on the design conditions. The data is being calculated for a whole year. Then, the cooling load assessment is carried out at several different times to find out the peak design load.

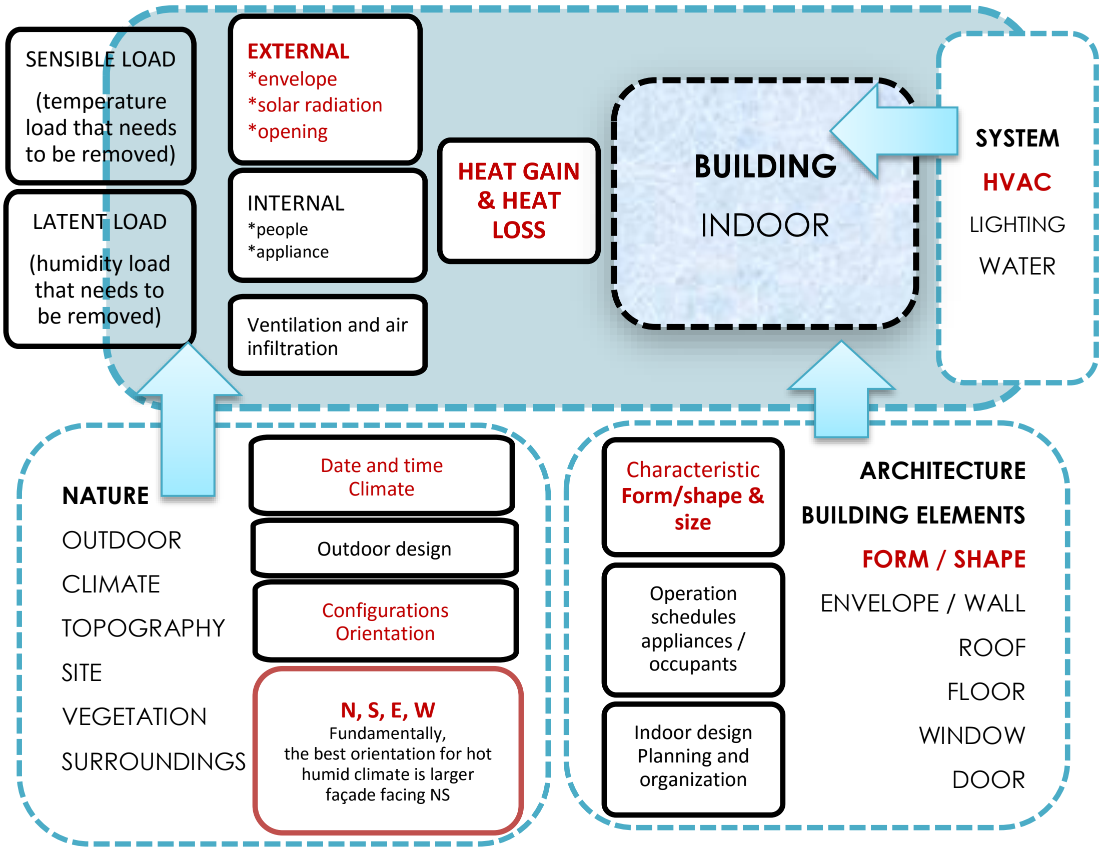

Figure 1.3 : Building characteristic of basic building forms and its variables

1.5.4 Limitation

The context of the study is based on the basic building forms. The building properties are drawn in Autodesk Revit and analysed using Autodesk Ecotect. The software allows users to design or draw a building, while at the same time have the access to the building information from the building models database.

The software is capable of planning and tracking the changes starting from the early design process until the project completion. It is capable of creating a parametric three-dimensional model that includes geometry and non-geometric design forms. Building performance is determined by proper cooling load calculation in the Autodesk Ecotect Software. Certain rules and constraints are added and manipulated. The building elements such as door, column, structure, space size and volume, envelope design, and types of material are set constant, while the building form is simulated into various types of basic forms and variables. Repeated process of energy analysis and experimentation for each building form need to be meticulously checked to ensure all analyses on each form are based on the same constant building variables.

The research involves manipulation of building forms and simulation in computer simulation software. The analysis results depend on the Autodesk Ecotect simulation program and CIBSE Admittance Method that are already installed in the software analysis calculation. This research is entirely carried out by using a computer simulation program of Autodesk Ecotect and Revit, thus bears the limitation of simulation tool used. By knowing the limitation, the research tries to validate the results with the actual building data. The results are based on the modelling data compared to the actual building data. In Chapter 3, a review of common research methods used by previous researchers and its justification for the selection of the present method will be discussed.

1.6 Significance of the Research

There are various studies on buildings related to energy efficiency and climate. However, the studies which investigate the basic building form feature in relation to lower cooling load in hot humid climate are very limited, especially in Malaysia and hot humid climate. This research investigates and highlights optimized building form and its design strategies that can improve energy efficiency in building and lower its cooling load in hot humid climate. Most studies have been focusing on how the building elements could achieve sustainable and green design through active and passive techniques. The exploration of building elements would be in terms of searching the best green material to be used as the structure, wall, ceiling, and roof. Others studies include on searching best optimum ratios of window to wall, surface to volume, shape and sizes of window, shading devices, and investigating best system in relation of better thermal comfort. While studies specific on cooling load have focused more on how a building design is related to envelope, facade, wall, and window which can lower the cooling load.

Based on the literature reviews, studies related to building energy efficiency explore more on the window as it is highlighted as the main source of heat gain and how solar heat gain affects thermal performance of a building. Most of the building form and geometrical exploration are related to parametric form and involve complex geometry. The reviews show complex generated geometry can improve building performance and its fabric can improve urban thermal performance. While in cold climate, the studies have observed building form does affects thermal performance but not specifically on the cooling load. Other numerous studies focused more on specific variables such as the design of the external and internal shading devices, façade, insulation, and materials of the building. Therefore, this research will highlight and explore the basic form and its variables that are mostly used by architects in local climate particularly Malaysia in reducing the cooling load. Based on the reviews, building geometry and shape show that the design variables such as the depth, width, angle, spacing, and colour of a building play important roles in determining which form responds better towards heat gain, cooling load, and thermal performance. The details in literature review will be explained further in Chapter 2 which shows that less study has been done on building form and cooling load.

This research is significant in order to respond to the problem statement and research issues. It will contribute to the body of knowledge by identifying the building form that have different cooling loads based on different surrounding arrangements. Secondly, this research will act as the guideline in starting the initial ideas of optimizing the building form design that have low cooling load for the architects. It is a need for early architectural design process in reducing cooling load (Demirbilek & Depczynski, 2008). Investigating optimal form either in relation to solar energy or cooling load that can initiate a design guideline in assisting architects is a great advantage (Caruso, Fantozzi, & Leccese, 2013). This research focuses on how the architect can explore design strategies based on the form and its components that help in improving energy performance. Most architect will interfere in the designing process of the building forms related to the characteristic and configuration of the building. The architects need a set of guidelines to work with and such guidelines should be performance oriented rather than prescriptive (Ballinger, 1984). In establishing these guidelines, it is essential to commence a considerable amount of research, both theoretical and empirical.

It is important for the architect to use the energy efficiency strategies and guidelines in the design process and eventually design a better building. During the initial stage of design process, architect deals with a lot of design issues such as physical, climatic, economic, social, and cultural factors. However, the architect should not ignore the importance of building form and its geometrical configurations from the beginning of the design process. The result of this research could greatly assist in designing medium height air-conditioned building form especially when energy conservation and sun prevention are the main concern. Such assistance uses an optimum geometric shape of building form and better placement of building space with the effect of lower cooling load.

1.7 Research Design Methodology

Conceptualization of this research design methodology is divided into four stages: 1. Background of study, 2. Literature review, 3. Data collection and 4. Data Analysis and Findings. The research design shows the flow of the research. The research design in stage one and stage two will highlight and review the relevant literature, model development, form exploration, energy analysis, and then present the results and conclusions as illustrated in Figure 1.4.

In stage three, the research will investigate and explore various basic forms that are commonly used in building design. These basic forms will be identified through literature reviews and identification of the common basic building forms in Malaysia. Later in stage four the cooling loads of chosen form will be estimated using the energy analysis software. The energy analysis software in stage four can store the building database such as material, structure specification, operating schedule, and weather data. The stored information can improve the understanding of the building form and provides reliable analysis. This feature also helps in proposing various building forms within various manipulated variables. The variables will be constrained or have constant dimension, size, and volume.

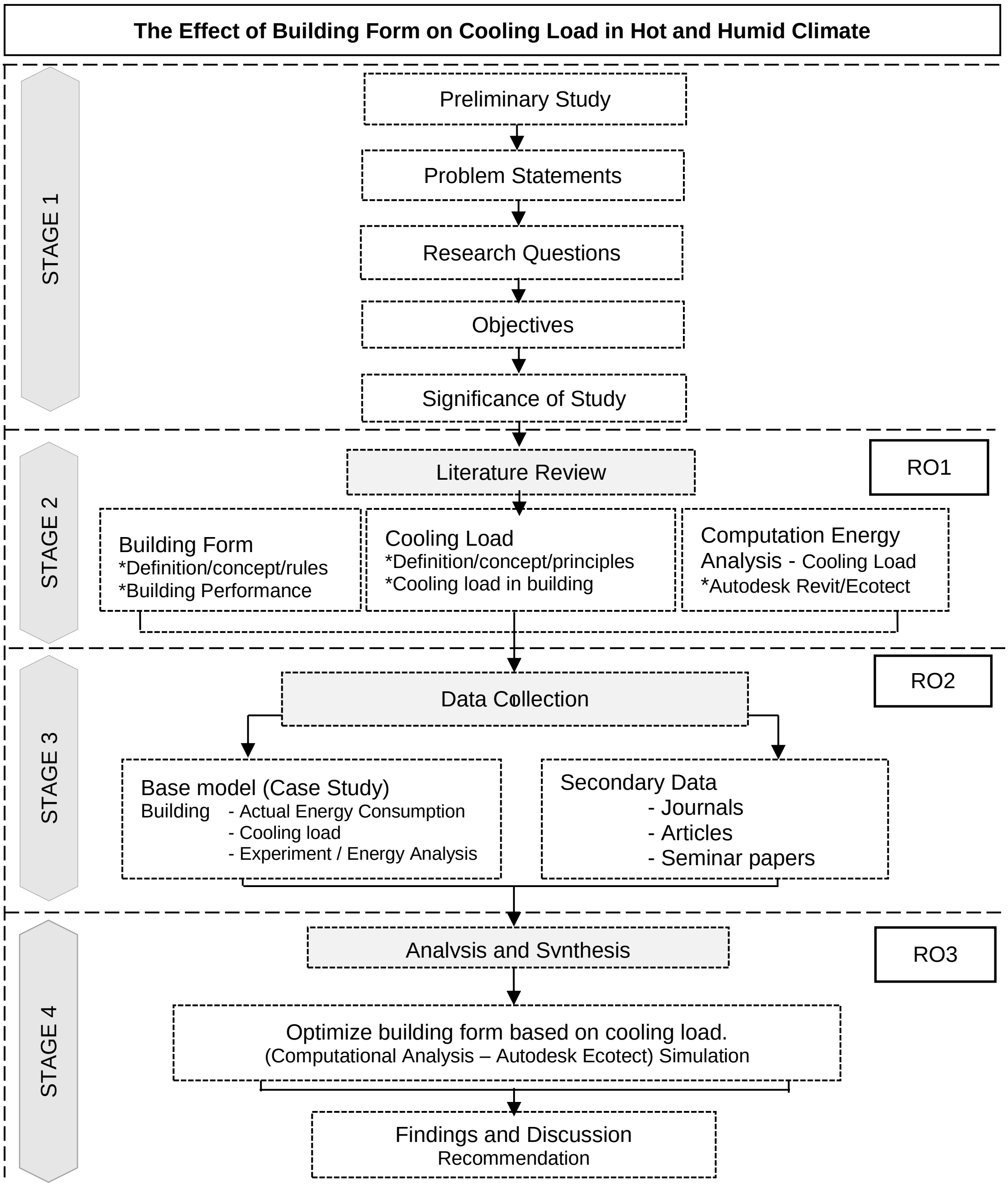

Figure 1.4 : Research design

In identifying an optimized form that has low cooling load, the basic building forms will be studied in stage four to demonstrate the process established. The basic forms studied will be constructed with a series of computer simulations which visualize the various variables of building form in relation to low cooling load. In search of optimum building form, the building will be modelled and reformed in Autodesk Revit. The detail energy analysis of the base model will be analysed in Autodesk Ecotect 2011. The computer simulation and the energy analysis will reveal the relationship between cooling load and building form. The result of the optimal form strategies can be integrate by the architect in the design process. This research design strategy is sufficient to achieve the aim and objectives of the study.

1.8 Conceptual Framework

The conceptual framework in Figure 1.5 illustrates the focus and the placement of the variables studied in this research. The cooling load, the building forms, the surface, volume and compactness, and the computer analysis will be highlighted in the research process.

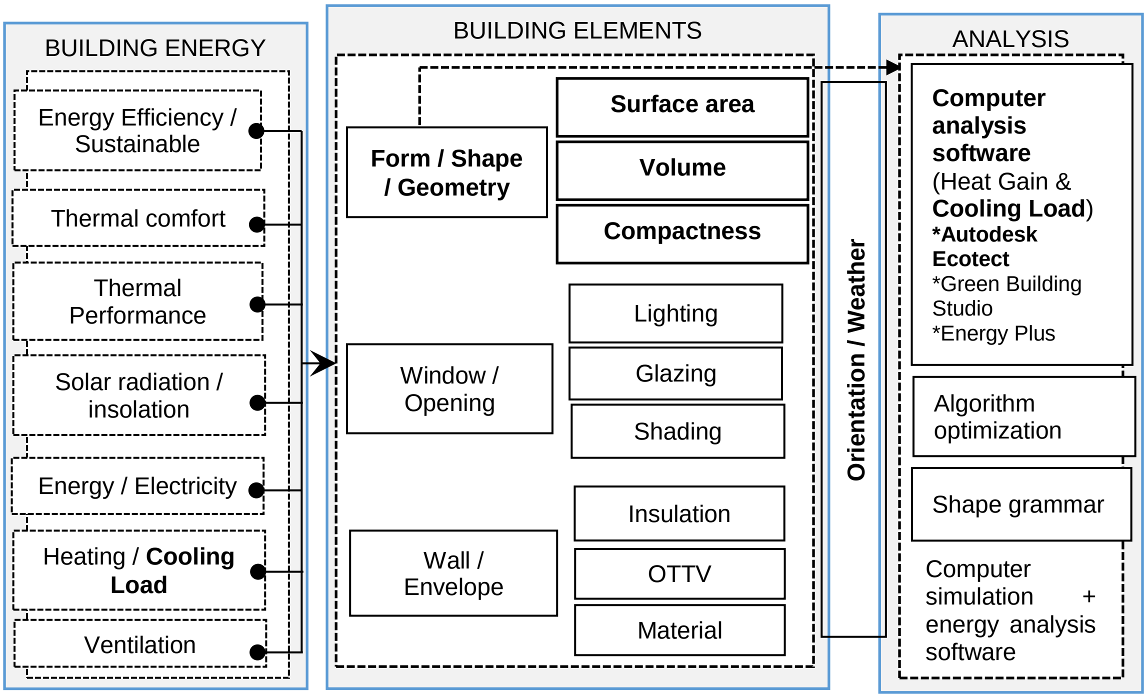

Figure 1.5 : Conceptual Framework

The research will focus on the cooling load, building form, orientation, and local climate, and will be simulated in the energy analysis software, Autodesk Ecotect 2011. The relationship of the building form, its variables, and cooling load will be studied.

1.9 Thesis Outline

The thesis comprises of five chapters and is organised in the following order. **Chapter 1** is the general introduction comprises of research background, problem statements, research aims, objectives, questions, scope and limitations, significance of the study, methodology, and conceptual framework.

Chapter 2 presents the literature review discussing the other studies related to form, shape, and energy efficiency. It also discusses what other researchers have explored. The chapter also describes and explains the concept of thermal performance, solar heat gain, solar radiation, the method of heat transfer, the calculation of cooling load, and its relation to building and environment.

Chapter 3 presents the methodology used in this research, including research design, framework, variables and parameters, and data collection. The chapter also discusses the usage of computer simulation and energy analysis software as the tool and method in gathering the data.

Chapter 4 organises the data collection for data analysis and the description of findings. Data analysis is categorized into three steps of basic form manipulations. The first steps is the exploration and understanding of basic forms having the same height level, volume and different surface. The second step is investigating further basic form by having different height level but same overall volume. The final step explores the same volume, height level and surface area. Different manipulations will shows different result of cooling load.

Chapter 5 presents the discussion of findings, conclusion, and future recommendations of the research topic.

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